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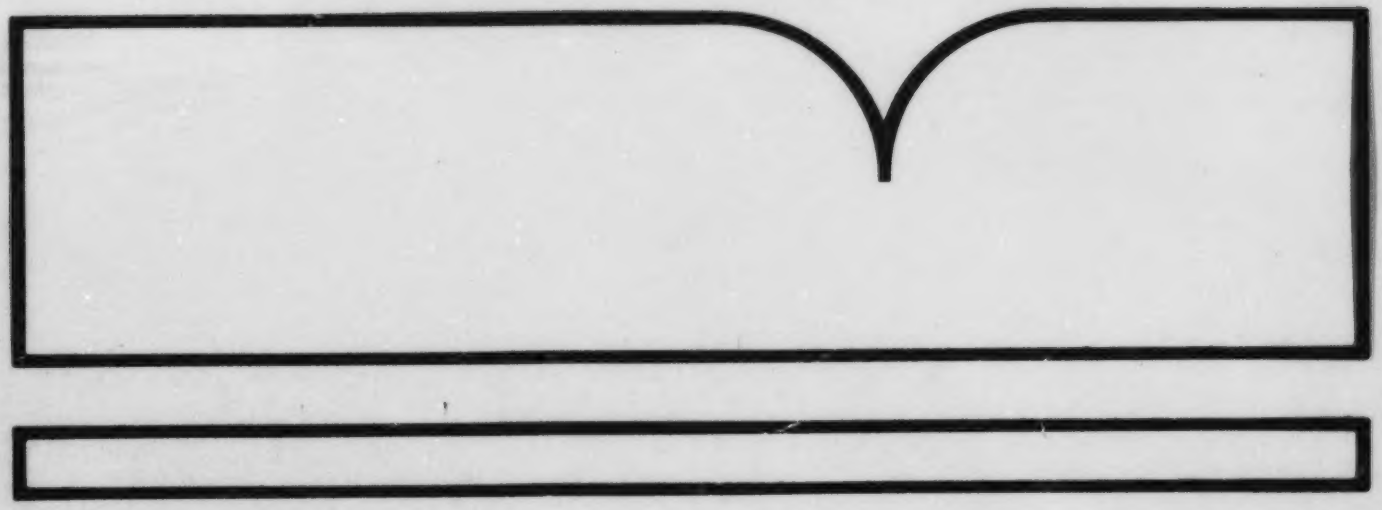

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EVALUATION OF GEOMEMBRANE SEAMS EXPOSED TO SELECTED ENVIRONMENTAL CONDITIONS

by

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16. ABSTRACT

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EVALUATION OF GEOMEMBRANE SEAMS EXPOSED TO SELECTED ENVIRONMENTAL CONDITIONS

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INTRODUCTION

An important aspect of hazardous waste treatment, storage, and disposal is the prevention of surface- and ground-water contamination by fluids containing hazardous constituents. Over the last few years, polymeric geomembranes have increasingly been specified and used in the construction of hazardous waste containment facilities, such as landfills and surface impoundments. A considerable number of laboratory tests and pilot-scale studies are currently being conducted to assess the effects of chemical waste products on the strength and durability of polymeric membrane liners; however, little has been done to assess the performance of the various factory and field seams used in joining the manufactured roll goods in the factory and the fabricated panels in the field.

The objective of this study is to evaluate bonded seams of commonly used geomembrane materials and the bonding methods employed. Tests will be carried out in an attempt to detect physical changes in these seams when exposed to selected chemicals and simulated environmental conditions. It is anticipated that physical property testing and chemical analysis will provide the

necessary data to assess the strength and durability of factory and field seams before, during, and after exposure. Such tests and the data gathered therefrom will eventually be used in preparing guidelines for engineers, specification writers, regulatory agencies, geomembrane fabricators, and installers to ensure that quality seams are produced for the intended use.

The project is now in progress and several tasks have already been completed. This paper describes the liner samples which were obtained, the immersion test setup, field seam fabrication, and ultraviolet (UV) exposure testing. Interim results are presented on several nondestructive test methods for evaluating the integrity of factory and field seam bonds. Also included are sections presenting future work in environmental cycling and heat aging of liner seam samples.

RESEARCH PROGRAM

The purpose of this study is to determine the chemical and physical effects of several types of simulated environmental exposure on the seams of various geomembrane materials. These exposures include: immersion of liner samples in six chemical solutions, tapwater and saturated brine, accelerated outdoor aging, freeze/thaw cycling, wet/dry cycling, and accelerated heat aging. After exposure of the samples, the effects will be analyzed by mechanical as well as analytical testing on the seam systems.

Materials Used in the Study

The geomembrane materials which are being tested were obtained from twelve industry representatives who manufacture and/or fabricate geomembranes commonly used in pollution and seepage control. Manufacturers were contacted and asked to participate in the study in an attempt to obtain a broad selection of recommended polymeric types (including reinforced and nonreinforced samples), scrim, and seaming techniques.

Polymer sheet materials submitted by industry for this project included the following:

High Density Polyethylene (HDPE)	30 mil, nonreinforced
	80 mil, nonreinforced
Linear Low Density Polyethylene (LLDPE)	30 mil, nonreinforced
Ethylene Propylene Rubber (EPDM)	40 mil, reinforced
Polyvinyl Chloride (PVC)	30 mil, nonreinforced
Chlorinated Polyethylene (CPE)	30 mil, nonreinforced
	36 mil, reinforced
Chlorosulfonated Polyethylene (CSPE)	36 mil, reinforced
Ethylene Interpolymer Alloy (EIA)	30 mil, reinforced

In addition, two or more sources submitted additional samples of PVC, HDPE, CPE, and CSPE (also commonly referred to as Hypalon) representing different manufacturing methods including varying scrim types and seaming methods.

The following factory and field seam types were submitted or field-fabricated for evaluation in the project:

Thermal - hot air

Thermal - dielectric

Thermal - hot wedge

Extrusion - fillet weld

Extrusion - lap weld

Bodied solvent adhesive

Solvent adhesive

Gumtape/cement

Vulcanized

A total of 37 combinations of sheet materials and seaming methods are being evaluated in the study.

Field Seam Fabrication

In addition to factory seams and polymer roll goods submitted by industry, field seams were constructed at the Bureau of Reclamation's Engineering and Research Center under representative field conditions.

The field seams were fabricated by a qualified third party commercial installer in accordance with manufacturers' instructions and utilizing manufacturer-supplied equipment and products where required. Some field seams

which could not be constructed at the Bureau were witnessed and collected at job sites by Bureau personnel. Figure 1 shows a typical section of seam being fabricated for this research.

Approximately 475 meters (1,500 linear feet) of different field seams, including solvent adhesive, bodied solvent adhesive, thermal and extrusion welds were completed for this project.

All seam systems were cut into large samples for environmental exposure. The nonreinforced seams were cut into 300-mm-(12-in-) wide samples in order to later yield twelve 25-mm-(1-in-) wide specimens for mechanical testing and the reinforced seams were cut into 450-mm-(18-in-) wide samples to provide four 50-mm-(2-in-) and eight 25-mm-(1-in-) wide specimens. To allow for possible edge effects due to the scrim exposure, 25-mm-(1-in-) of each edge of the scrim-reinforced samples was cut off and thrown away. All samples were attached with polypropylene ties to fiberglass rods for exposure testing, as shown in Figure 2.

Chemical and Aqueous Solution Immersions

The six chemical solutions chosen for this research program include the following:

10% phenol,

10% hydrochloric acid,

10% sodium hydroxide,

10% methyl ethyl ketone,

5% furfural, and

100% methylene chloride.

These chemicals were chosen to represent a wide range of chemical groups, such as organic acid, inorganic acids and bases, halogenated hydrocarbons, ketones and aldehydes and should provide a range of effects on the liner materials. Methylene chloride is not soluble in water; therefore, pure solvent was used to prevent the problem of phase separation. Pure chemicals or aqueous chemical solutions were selected for testing over simulated or actual wastes from waste sites to simplify verification of testing procedures. The use of representative groups of chemicals also allows for reasonable interpretation of the data.

Chemical, brine, and water immersion of seam samples are being accomplished in covered 170-liter (45-gallon) polyethylene and polypropylene tanks as shown in Figure 2. At the end of specified exposure periods, samples will be retrieved for mechanical and analytical testing. In parallel with the tank immersions, smaller coupons of the liner materials are immersed in small clear glass jars for periodic weighings and thickness measurements. The smaller coupons allow for easier inspection of the materials for obvious excessive degradation, swelling, or change in color or surface texture. If

any accelerated response is observed in the coupons, the seam samples will be removed from the larger tanks before they are destroyed completely. The ratio of the volume of liquid to the surface area for each coupon is 6.2 mL/cm^2 (40 mL/in^2).

Three tanks of room temperature tapwater and six tanks of saturated sodium chloride brine solution (three tanks at room temperature and three at 50^oC (122^oF)) are set up for immersing some of the seam samples. The remaining samples are either placed in running tapwater for 6-month saturation before begining 50 cycles of freeze-thaw and wet-dry testing or set aside for heat aging. Double-sided exposure of all samples is being used to accommodate the large number of samples in minimum space. The accelerated effect of double-sided exposure compared to one-sided exposure reduces the time it would take to see any effects the liquids may have on the samples.

Accelerated Outdoor Exposure

In addition to the above exposure conditions, the Desert Sunshine Exposure Test (DSET) Laboratories in Phoenix, Arizona, are performing accelerated outdoor sunlight exposure testing on representative seam samples. The exposures are being accomplished on the EMMAQUA(R) accelerated weathering test machine located at the test facility. Figure 3 shows one of the EMMAQUA machines which are capable of tracking the sun and focusing the suns rays on the specimens for optimum ultraviolet (UV) exposure.

The seam samples are 125-mm (5-in) in exposed seam length. After one year of actual sunlight exposure (approximately equal to seven to eight years of weathering) the samples will be returned to the Bureau and tested for peel strength retention and observed for any obvious deterioration.

Accelerated Environmental Cycling and Heat Aging

In an effort to determine the effects of cyclic stress and heat on the various seam systems, short term freeze/thaw and wet/dry cycling will be carried out on the seam samples that have been submerged in tapwater for six months and heat aging will be carried out on the samples which were set aside. Presently, there is little information available for determining the long-term effects on physical properties in subfreezing temperatures, especially for those membranes that have a tendency to absorb water. Seam samples will be subjected to alternating cycles of freezing for 24 hours and thawing for 24 hours. They will be tested after intervals of 10, 20 and 50 cycles. Wet/dry cycling will represent the fluctuating liquid/liner/air interface where severe weathering can take place. Other seam samples will be tested after 10, 20 and 50 wet/dry cycles. These cycles alternate 24 hours of water submersion with 24 hours of air drying at room temperature.

Many liner systems are installed in the warmer climates of the world where higher temperatures often may be destructive to the liner material. Seam samples will be subjected to 70°C (158°F) for periods of 4, 8 and 13 weeks of oven aging in an effort to provide an accelerated test of long-term heat effects on the seam systems.

Physical/Mechanical Testing

At the end of 3-month, 6-month, and 12-month chemical, brine, and water exposures and after completion of the required environmental conditioning intervals, the following physical and mechanical tests will be performed to determine changes in physical properties:

1. Volume (thickness) and weight - Coupon samples were measured for volume and thickness before immersion. Exposed coupon samples are measured every week for the first month, monthly for the next 3 months, and quarterly thereafter.

2. Dynamic tensile shear testing - 50-mm-(2-in-) wide reinforced or 25-mm-(1-in-) wide nonreinforced seam specimens are tested in tensile shear using dynamic loading at a low strain rate of 0.8 mm/s (2 in/min). The reinforced samples are wider for tensile testing in an effort to eliminate edge effects due to the scrim reinforcement. Results will be in N/m (lb_f/in) width of seam.

3. Dynamic peel testing - 25-mm-(1-in-) wide specimens are subjected to 180^o peel at a strain rate of 0.8 mm/s (2 in/min). Results will be in N/m (lb_f/in) width of seam.

4. Static dead load peel testing at elevated temperature - 25-mm-(1-in-) wide specimens are subjected to a 180° peel dead load equivalent to approximately five percent of the material's breaking strength per inch of width at a temperature of 50°C (122°F). Results will be expressed by pass/fail, time to failure, and mode of failure.

Test results of exposed seam samples will be compared to the test results of original unexposed seam samples for all tests. The mode of failure will be evaluated as well as the numerical results of shear, peel and dead load in N/m (lb_f/in) of seam width. Figures 4 and 5 show the test equipment used for static and dynamic tensile testing.

Nondestructive Test (NDT) Methods

As a part of the EPA project, factory and field seams were evaluated using six known nondestructive test (NDT) techniques. The six techniques evaluated include the following:

- Acoustic method - ultrasonic pulse echo (5- to 15- MHz)
- Acoustic method - continuous wave resonant frequency (167 KHz)
- Air lance- 345 kPa (50 lb/in^2)
- Vacuum chamber
- Double seam pressurization
- Mechanical point stress

The two acoustic methods were performed at the Bureau of Reclamation with equipment and personnel supplied by Battelle Pacific Northwest Laboratories, Richland, Washington. The remaining techniques were performed and evaluated by Bureau personnel.

In general, air lance, vacuum chamber, and mechanical point stressing work well on most seam types. Air lance testing utilizes a jet of 345 kPa (50 psi) air directed at the seam edge through a 4.76 mm (3/16") nozzle. This method detects unbonds, however it was found to be unsatisfactory on the stiffer HDPE material and thicker reinforced sheets. Mechanical point stressing utilizes a blunt instrument, such as a dull screwdriver, to check the bonded edge. This method is not applicable to all geomembranes, especially the thinner ones susceptible to puncture. Vacuum chamber testing should be limited to 30 mil and thicker liners due to the deformation experienced by thin liners under relatively low vacuum. Double seam pressurization is presently limited to the dual hot wedge type of seam used on HDPE; however, the technique (which simply involves injecting a specified air pressure between parallel seam areas and examining for leaks or drop in pressure) could work on other types of dual seams as an integrity check.

The continuous wave resonant frequency, also called ultrasonic impedance plane (UIP) technique testing was found useful in detecting unbonded areas in all types of bonded lining materials including the various scrim-reinforced sheets. As a check on electronic methods, specimens were cut out of areas detected on the UIP as being unbonded and these specimens were tested in

mechanical peel. The results of this testing confirmed the accuracy of the UIP when used on reinforced lining seams. The ultrasonic pulse echo technique was found useful in detecting unbonded areas in the nonreinforced sheet materials but not in the scrim-reinforced sheet materials. Both electronic NDT methods need improvement in field application to provide faster test methods. Table 1 outlines the recommended NDT methods for the various lining material types and thicknesses based on this research.

It should be pointed out that these methods only check for bonding of lining material. No correlation between bonding and seam strength can be made from these nondestructive test methods alone.

Analytical Testing

After six months and one year of exposure to chemicals, tapwater, brine, and accelerated outdoor exposure, samples of each polymer sheet material and seam interface through the thickness of the seam, will be examined for changes in chemical composition using Gas Chromatography (GC) and Gas Chromatography/Mass Spectrometry (GC/MS). These analyses will hopefully detect any subtle changes in the chemical composition of the polymer sheet material and bonding system which may have occurred. This method could predict the potential for deterioration of the sheet material or seam. It is important to note very valuable potential use of GC/MS analyses in the early detection of changes in a given polymer with time. This may enable industry and end users to detect problems due to aging or specific environmental exposures.

RESEARCH COORDINATION

The EPA Municipal Environmental Research Laboratory is coordinating this research with other EPA-funded projects in an effort to provide meaningful and comparative test data. Some aspects of these projects are to study microscopic changes in polymer sheet samples after one-sided and double-sided exposure to chemicals. Another focus is on evaluating service life and developing prediction methods based on chemical and physical properties. On a wider scale, the EPA sponsored a meeting with other government agencies who are doing similar research on geomembranes for use in waste containment. Topics for on-going or planned geomembrane research include the following:

- Dead Load Testing - Seams
- Evaluation After Aging - Seams
- Nondestructive Seam Testing
- Field Seaming Procedures/Evaluation
- GC/MS Analysis of Geomembranes
- Geomembrane Failure Mechanisms
- Polymer Chemistry vs. Aging
- Chemical Compatibility/Resistance
- Accelerated Aging of Geomembranes
- Geomembrane/Soil Cover Interaction
- Impoundment Construction Techniques
- Prevention of H_2O Contamination
- Gas Desulpherization of Waste/Use of Geomembranes
- Leak Detection Techniques

- Hazardous Waste/Geomembrane Compatibility
- Evaluation of Old Installations
- Geomembrane Repair Procedures
- Geomembrane Covers - Landfills
- Subgrade Anomaly Conformance
- Restoration of Old Installations
- Utilities Waste Containment
- Soil Cover - Seepage Prevention
- Soil Cover - Infiltration Characteristics
- Prediction of Subsidence - Soil/Geomembrane Cover
- Low-Level Radioactive Waste Containment
- Geomembrane Cost Analysis/Cost Effectiveness
- Determination of Effective Life of Geomembranes

Meetings and interactions with other research groups help direct this project and future EPA projects so that results are comparable and complementary.

FORMULATION OF GUIDELINES

The goal of EPA's seam program is to examine all aspects of seaming and seam durability when using geomembranes for pollutant control in order to provide information on the performance, selection and installation of various lining materials. The information will assist the end users in determining what liner(s) would be effective in containing specific hazardous wastes and ensure proper construction and installation for maintaining the integrity of the liner during daily operations. Compiling the data from this project with

others and making it available to the end users may reduce the potential for leachate migration through seam failures to ground-water and surface-water sources.

Table 1. - Recommended NDT Methods Based on this Research

Geomembrane system	Thickness (mils)*	Ultrasonic pulse echo (5-15 MHz)	Continuous wave resonant Frequency (167 kHz)	Air lance	Vacuum chamber	Double seam Pressurization	Mechanical point stress
Reinforced Hypalon and CPE	30		*	*	*		*
	36		*	*	*		*
	45		*	*	*		*
	60		*		*		*
Nonreinforced CPE	20	*	*	*			
	30	*	*	*	*		*
Nonreinforced PVC	20	*	*	*			
	30	*	*	*	*		*
	45	*	*	*	*		*
HDPE HDPE-A LLDPE	20	*	*		*		*
	30	*	*		*	*	*
	40	*	*		*	*	*
	60	*	*		*	*	*
	80	*	*		*	*	*
	100	*	*			*	*
Reinforced EPDM and BUTYL	30			*	*		*
	45			*	*		*
	60				*		*
EIA	38				*		*

*1 mil = .0254 mm

LIST OF FIGURES

Figure 1 Fabrication of a typical seam section

Figure 2 Typical sample arrangement in one 45-gallon tank

Figure 3 EMMAQUA test machine for accelerated outdoor exposure

Figure 4 Typical dynamic peel test being performed on an Instron 1123 tensile test machine

Figure 5 Static dead load test apparatus showing temperature control chamber and automated timing system

Figure 1

Figure 3

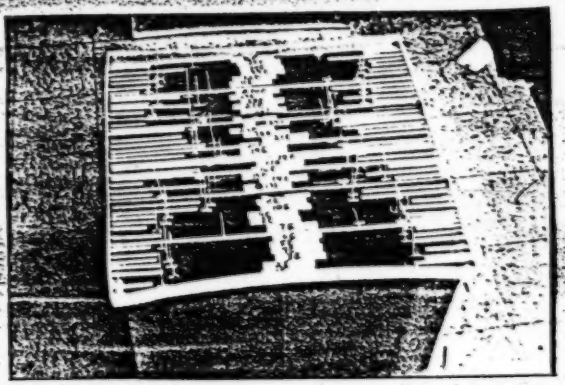
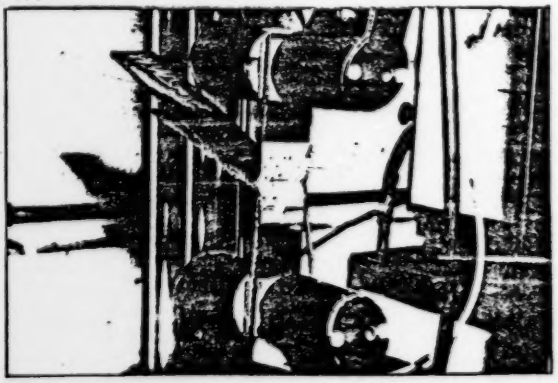


Figure 2



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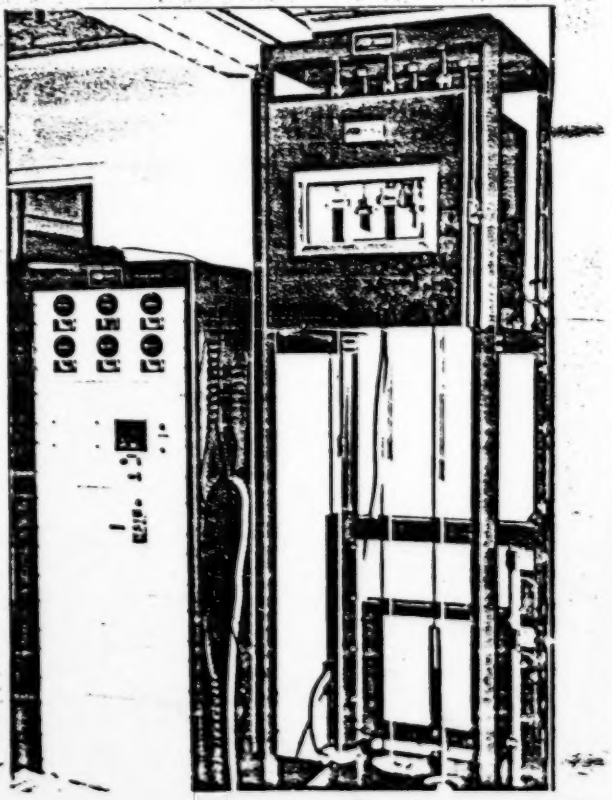

Figure 5